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# A REVIEW OF ARSENIC HAZARDS TO PLANTS AND ANIMALS WITH EMPHASIS ON FISHERY AND WILDLIFE RESOURCES

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aquatic weed control may be harmful to several species of freshwater teleosts, including bluegills, flagfish (*Jordanella floridae*), fathead minnows (*Pimephales promelas*), and rainbow trout (*Oncorhynchus mykiss*) (Table 4). Fish exposed to 1 to 2 mg total As/L for 2 to 3 days may show one or more of several signs: hemorrhagic spheres on gills, fatty infiltration of the liver, and necrosis of heart, liver, and ovarian tissues (NRCC, 1978). In green sunfish (*Lepomis cyanellus*), hepatocyte changes parallel arsenic accumulation in the liver (Sorensen et al., 1985). Organoarsenicals are usually eliminated rapidly by fish and other aquatic fauna. Rainbow trout, for example, fed a marine diet containing 15 mg organic As/kg had only negligible tissue residues 6 to 10 days later, although some enrichment was noted in the eyes, throat, gills, and pyloric caeca (Pershagen and Vahter, 1979). Oral administration of sodium arsenate to estuary catfish (*Cnidoglanis macrocephalus*) and school whiting (*Sillago bassensis*) resulted in tissue accumulations of trimethylarsine oxide. Arsenobetaine levels, which occur naturally in these teleosts, were not affected by  $As^{+5}$  dosing. The toxicity of trimethylarsine oxide is unknown, but the ease with which it can be reduced to the highly toxic trimethylarsine is cause for concern (Edmonds and Francesconi, 1987).

#### 6.4. Birds

Signs of inorganic trivalent arsenite poisoning in birds (muscular incoordination, debility, slowness, jerkiness, falling, hyperactivity, fluffed feathers, drooped eyelids, huddled position, unkempt appearance, loss of righting reflex, immobility, seizures) were similar to those induced by many other toxicants and did not seem to be specific for arsenosis. Signs occurred within 1 hr and death within 1 to 6 days after administration; remission took up to 1 month (Hudson et al., 1984). Internal examination suggested that the lethal effects of acute inorganic arsenic poisoning were due to the destruction of blood vessels lining the gut, which resulted in decreased blood pressure and subsequent shock (Nyström, 1984). For example, coturnix (*Coturnix coturnix*) exposed to acute oral doses of  $As^{+3}$  showed hepatocyte damage (swelling of granular endoplasmic reticulum); these effects were attributed to osmotic imbalance, possibly induced by direct inhibition of the sodium pump by arsenic (Nyström, 1984).

Arsenic, as arsenate, in aquatic plants (up to 430 mg As/kg plant dry weight) from agricultural drainwater areas can impair normal development of mallard ducklings (Camardese et al., 1990) (Table 5). Pen studies with ducklings showed that diets of 30 mg As/kg ration adversely affects growth and physiology, and 300 mg As/kg diet alters brain biochemistry and nesting behavior. Decreased energy levels and altered behavior can further decrease duckling survival in a natural environment (Camardese et al., 1990).

Western grasshoppers (*Melanophis* spp.) poisoned by arsenic trioxide were fed, with essentially no deleterious effects, to nestling northern bobwhites (*Colinus virginianus*), mockingbirds (*Mimus polyglottos*), American robins (*Turdus migratorius*), and other songbirds (NAS, 1977). Up to 134 poisoned grasshoppers, containing a total of about 40 mg arsenic, were fed to individual nestlings without any apparent toxic effect. Species tested that were most sensitive to various arsenicals

**Table 5 Lethal and Sublethal Effects of Various Arsenicals on Selected Species of Birds**

Species and Arsenic Compound	Effect	Reference <sup>a</sup>
Chukar, <i>Alectoris chukar</i> Silvisar-510 (mixture of cacodylic acid and tri-ethanolamine cacodylate)	Single oral LD <sub>50</sub> dose of about 2000 mg/kg body weight (BW); signs of poisoning evident within 10 minutes and mortalities within 1 to 2 days; remission took up to one month	1
Mallard, <i>Anas platyrhynchos</i> Sodium arsenate	Ducklings were fed 30, 100, or 300 mg As/kg diet for 10 weeks. All treatment levels produced elevated hepatic glutathione and ATP concentrations and decreased overall weight gain and rate of growth in females. Arsenic concentrations were elevated in brain and liver of ducklings fed 100 or 300 mg/kg diets; at 300 mg/kg, all ducklings had altered behavior, i.e., increased resting time; male ducklings had reduced growth	2
Sodium arsenite	323 mg/kg BW is LD <sub>50</sub> acute oral value	1, 3, 4
Sodium arsenite	500 mg/kg diet is fatal to 50% in 32 days; 1000 mg/kg diet fatal to 50% in 6 days	3
Sodium cacodylate	1740 to 5000 mg/kg diet not measurably harmful to ducklings in 5 days	5
Silvisar 510	Single oral LD <sub>50</sub> > 2400 mg/kg BW; regurgitation and excessive drinking noted	1
Lead arsenate	5000 mg/kg diet not fatal in 11 days	3
Copper acetoarsenite	5000 mg/kg diet fatal to 20% in 11 days	3
California quail, <i>Callipepla californica</i> Sodium arsenite	Single oral LD <sub>50</sub> value of 47.6 mg/kg BW	1
Northern bobwhite, <i>Colinus virginianus</i> Copper acetoarsenite	480 mg/kg in diet fatal to 50% in 11 days	3
Sodium cacodylate	1740 mg/kg in diet for 5 days produced no effect on behavior, no signs of intoxication, and negative necropsy	5

Table 5 (Continued)

Species and Arsenic Compound	Effect	Reference <sup>a</sup>
Monosodium methanearsonate, $\text{CH}_3\text{AsNaO}_2$ Chicken, <i>Gallus gallus</i>	Single oral $\text{LD}_{50}$ dose of 3300 mg/kg BW	5
Inorganic trivalent arsenite	Up to 34% dead embryos at dose range of 0.01–1 $\mu\text{g As}^{+3}$ /embryo; threshold for malformations at dose range 0.03–0.3 $\mu\text{g}/\text{embryo}$	4
Inorganic pentavalent arsenate	Up to 8% dead at dose range 0.01–1 $\mu\text{g As}^{+5}$ /embryo; threshold for malformations at dose range 0.3–3 $\mu\text{g}/\text{embryo}$	4
Disodium methylarsenate	Teratogenic to embryos when injected at 1 to 2 mg/egg	4, 5
Sodium cacodylate	Developmental abnormalities at embryonic injected doses of 1 to 2 mg/egg	5
Dodecylamine p-chlorophenylarsonate	At dietary levels of 23.3 mg/kg, liver residues were 2.9 mg/kg fresh weight (FW) at 9 weeks. No ill effects noted	6
3-Nitro-4-hydroxyphenylarsonic acid	At 18.7 mg/kg diet for 9 weeks, liver residues of 2.4 mg/kg FW. Those fed diets containing 187 mg/kg for 9 weeks had no ill effects; liver content of 7.5 mg/kg FW	6
3-Nitro-4-hydroxyphenylarsonic acid	$\text{LD}_{50}$ dose of 33 mg/kg BW (single oral) or 9.7 mg/kg BW (intraperitoneal injection)	3
Arsanilic acid	Fed diets containing 45 mg/kg for 9 weeks; no effect except slightly elevated liver content of 1.2 mg/kg FW. At dietary levels of 455 mg/kg, liver residues were 6.4 mg/kg FW after 9 weeks; no other effects evident	6
Cacodylic acid	Dosed orally without effect at 100 mg/kg BW daily for 10 days	5
Chickens, <i>Gallus</i> spp.		
Arsanilic acid	50% excreted in 36 to 38 hr	4
Arsenate	50% excreted in 60 to 63 hr	4
Turkey, <i>Meleagris gallopavo</i>		
3-Nitro-4-hydroxyphenylarsonic acid	Single oral $\text{LD}_{50}$ dose of 17.4 mg/kg BW	3
Brown-headed cowbird, <i>Molothrus ater</i>		
Copper acetoarsenite	All survived 11 mg/kg diet for 6	

Table 5 (Continued)

Species and Arsenic Compound	Effect	Reference <sup>a</sup>
	months; maximum whole body residue of 1.7 mg As/kg dry weight (DW)	3
Copper acetoarsenite	All survived 33 mg/kg diet for 6 months (whole body content of 6.6 mg As/kg DW) or 7 months (8.6 DW)	3
Copper acetoarsenite	99.8 mg/kg in diet fatal to 50% in 11 days	3
Copper acetoarsenite	100 mg/kg in diet for 3 months fatal to 100%; tissue residues, in mg/kg DW, of 6.1 in brain, 40.6 in liver	3
Gray partridge, <i>Perdix perdix</i>		
Lead arsenate	300 mg/kg BW fatal in 52 hr	3
Ring-necked pheasant, <i>Phasianus colchicus</i>		
Sodium arsenite	Single oral dose of 386 mg/kg BW is LD <sub>50</sub> value	1
Copper acetoarsenite	Single oral dose of 1403 mg/kg BW is LD <sub>50</sub> value	4
Lead arsenate	4989 mg/kg in diet fatal	3

<sup>a</sup> 1, Hudson et al., 1984; 2, Camardese et al., 1990; 3, NAS, 1977; 4, NRCC, 1978; 5, Hood, 1985; 6, Woolson, 1975.

were the brown-headed cowbird (*Molothrus ater*), with an LD<sub>50</sub> (11-day) value of 99.8 mg of copper acetoarsenite/kg diet; California quail (*Callipepla californica*), with an LD<sub>50</sub> single oral dose value of 47.6 mg of sodium arsenite/kg body weight; and chicken with 33 and turkey with 17.4 mg/kg body weight of 3-nitro-4-hydroxyphenylarsonic acid as a single oral LD<sub>50</sub> dose (Table 5).

Chickens rapidly excrete arsenicals; only 2% of dietary sodium arsenite remained after 60 hr (NAS, 1977), and arsanilic acid was excreted largely unchanged (Woolson, 1975). Excretion of arsanilic acid by chickens was affected by uptake route: excretion was more rapid when administration was by intramuscular injection than when it was oral (NRCC, 1978). Studies with inorganic As<sup>+5</sup> and chickens indicated that (1) arsenates rapidly penetrated the mucosal and serosal surfaces of epithelial membranes, (2) As<sup>+5</sup> intestinal absorption was essentially complete within 1 hr at 370 mg As<sup>+5</sup>/kg body weight but only 50% complete at 3700 mg/kg body weight, (3) vitamin D<sub>3</sub> was effective in enhancing duodenal As<sup>+5</sup> absorption in rachitic chicks, and (4) As<sup>+5</sup> and phosphate did not appear to share a common transport pathway in the avian duodenum (Fullmer and Wasserman, 1985).

**Table 7 Proposed Arsenic criteria for Protection of Selected Natural Resources and Human Health**

Resource, Criterion, and Other Variables	Criterion or Effective Arsenic Concentration (reference)
<b>AQUATIC LIFE</b>	
Freshwater biota: medium concentrations	Four-day mean water concentration not to exceed 190 $\mu\text{g}$ total recoverable inorganic $\text{As}^{-3}/\text{L}$ more than once every 3 years; one-hour mean not to exceed 360 $\mu\text{g}$ inorganic $\text{As}^{-3}/\text{L}$ more than once every 3 years Insufficient data for criteria formulation for inorganic $\text{As}^{+5}$ , or for any organoarsenical (EPA, 1985)
Freshwater biota: tissue residues	Diminished growth and survival reported in immature bluegills when total arsenic residues in muscle > 1.3 mg/kg fresh weight (FW) or > 5 mg/kg in adults (NRCC, 1978)
Saltwater biota: medium concentrations	Four-day average water concentration not to exceed 36 $\mu\text{g}$ $\text{As}^{+3}/\text{L}$ more than once every 3 years; one-hour mean not to exceed 69 $\mu\text{g}$ $\text{As}^{+3}/\text{L}$ more than once every 3 years; insufficient data for criteria formulation for inorganic $\text{As}^{+5}$ , or for any organoarsenical (EPA, 1985)
Saltwater biota: tissue residues	Depending on chemical form of arsenic, certain marine teleosts may be unaffected at muscle total arsenic residues of 40 mg/kg FW (NRCC, 1978)
<b>BIRDS</b>	
Tissue residues	Residues, in mg total As/kg FW, in liver or kidney in the 2–10 range are considered elevated; residues > 10 are indicative of arsenic poisoning (Goede, 1985)
Mallard, <i>Anas platyrhynchos</i> Sodium arsenate in diet	Reduced growth in ducklings fed > 30 mg As/kg diet (Camardese et al., 1990)
Turkey, <i>Meleagris gallopavo</i> Arsanilic acid in diet	Maximum dietary concentration for turkeys < 28 days old is 300 to 400 mg/kg feed (NAS, 1977)
Phenylarsonic feed additives for disease control and improvement of weight gain in domestic poultry; safe dietary levels	Maximum levels in diets, in mg/kg feed, are 50 to 100 for arsanilic acid, 25 to 188 for 3-nitro-4-hydroxyphenylarsonic acid (for chickens and turkeys, not

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